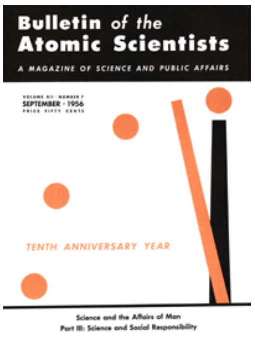

Bulletin of the Atomic Scientists

ISSN: 0096-3402 (Print) 1938-3282 (Online) Journal homepage: http://www.tandfonline.com/loi/rbul20

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To cite this article: Ralph E. Lapp (1956) The “Humanitarian” H-Bomb, Bulletin of the Atomic Scientists, 12:7, 261-264, DOI: 10.1080/00963402.1956.11453741

To link to this article: https://doi.org/10.1080/00963402.1956.11453741

Published online: 15 Sep 2015.

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The "Humanitarian" H-Bomb

RALPH E. LAPP

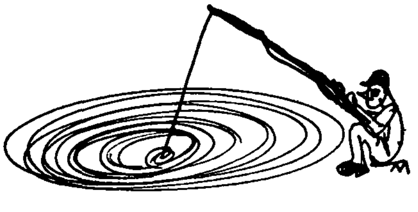
OPERATION *Redwing*, the U.S. Pacific bomb tests for 1956, was concluded in mid-summer and radiation experts are waiting for the dust to settle. *Project Sunshine*, the AEC's task force for studying long-term global fall-out, is already at work measuring the gradual deposition of this radioactive dust. However, the global fall-out is so slow that it will take some months before accurate measurements can be made.

Even before the dust had settled, Admiral Lewis L. Strauss had stirred up a cloud of controversy about "clean" and "dirty" bombs. The chairman of the AEC proceeded to invent humanitarian H-bombs. We shall examine some of the structural and operational features of these weapons.

We shall put maximum emphasis upon high-yield weapons loosely called bombs. This means the megaton-class weapon whose power is measured in millions of tons of TNT equivalent. Other names for this type of bomb are "super" and thermonuclear weapon. For an "official" definition of the term we quote Adm. Lewis L. Strauss' statement of June 13, 1956 before the House Appropriations Committee: ". . . the thermonuclear weapon is the weapon which derives its explosive power from the fusion or bringing together of nuclei of atoms at the other end of the atomic scale, that is to say, the light elements such as deuterium, which is an isotope of hydrogen."

If Adm. Strauss's definition of the thermonuclear weapon were strictly true then the so-called H-bomb would be a clean weapon because fusion of hydrogen isotopes produces helium, which is *not* radioactive. Neither does it produce much "induced" radioactivity in the surroundings. Dr. Willard F. Libby affirmed this in his testimony early this year before the Holifield civil defense subcommittee when he said: "The principal radioactivities are produced by nuclear weapons themselves and not in the surroundings." Dr. Libby acknowledged the possibility of thermonuclear neutrons hitting the ground (in the case of a low-level burst), but emphasized that it was "the radioactivity generated in the weapon" which was responsible for the fall-out hazard.

Ralph Lapp, physicist and author, continues his discussion of thermonuclear weapons and radioactive fall-out. This article is the fifth in the series.



The Genesis of Fall-out

We thus have something of a puzzle. Radioactivity actually *is* generated by the thermonuclear weapon, which by Adm. Strauss' definition should be a clean bomb. What then makes the H-bomb radioactive? The answer has already been given in earlier articles in the *Bulletin*.[1] It is that the megaton-class weapon is a three-stage bomb.

Stage I involves the firing of an inner "nuke" or fissionable core of U-235 or plutonium. This is the A-bomb trigger, which serves two purposes. First, it initiates an atomic explosion which produces multimillion degree heat. Second, it releases a swarm of fission neutrons which flash out and hit the liner of the bomb. Thus the A-core produces heat and neutrons.

Stage II is, itself, twofold. It takes place in the liner contiguous with the A-trigger, and consisting of lithium hydride. The latter is a chemical compound, formed by the light element lithium and the heavy isotopes of hydrogen. Its important constituent is lithium-6 deuteride, the compound of the isotopes, Li^6 and H^2 (deuterium). The first reaction takes place when the fission neutrons from Stage I strike the lithium. It happens that the light lithium isotope Li^6 has a very high cross-section for a neutron reaction which splits lithium-6 into an atom of tritium[2] and an atom of helium. These two products generated by the neutron reaction fly apart with considerable violence. Tritium is, in fact, born with an energy of 3 million electron volts.

Hydrogen Fusion

The stage is now set for the thermonuclear reaction. It is well known that the two heavy isotopes of hydrogen, deuterium and tritium, fuse faster than any other pair of isotopes. Because of the manner of its birth, the lithium-spawned tritium is "heated up" and can make high speed collisions with atoms in the neighborhood. These atoms include lithium and deuterium, and perhaps some "seed" tritium (i.e., tritium put into the bomb, in contrast to that generated by the explosion). Tritium fuses with deuterium to form helium, but only if it makes the right kind of collisions. Many tritium atoms would be expected to slow down without fusing unless very high temperatures were attained.

[1] See *Bulletin*, November 1954, pp. 349–51; February 1955, pp. 44–51; June 1955, pp. 206–09; and November 1955, pp. 339–43.

[2] The Castle Bravo Test caused a rain-out of water containing tritium for a period of several months after the spring 1954 explosion of a dirty superbomb.

The fusion reaction of T and D produces not only helium, but also a very fast neutron. Actually, the neutron runs off with the lion's share of the fusion energy. Openly published measurements of these reactions show that appreciable yields of 14 Mev (fourteen million electron volt) neutrons are obtained. If these extremely fast neutrons were not somehow trapped and made to yield up their energy, the latter would be lost to space.

The Outer Jacket

Stage III provides for the capture of the would-be run-away fast neutrons. It takes place in the outer mantle or jacket of the reacting bomb. Theoretically, one might suggest surrounding the inner core with a "reflector" which would encage the neutrons. But, practically, why not make the fly-away neutrons do some work?

Neutrons can cause fission. Almost everyone knows that neutrons released in fission can perpetuate a chain reaction by fissioning other U-235 or plutonium atoms. What is less well known is that if the neutrons are fast enough they can tap the energy of ordinary uranium or thorium. Neutrons produced by the deuterium-tritium fusion are more than adequate for the fast fission of ordinary uranium. Natural uranium is 99.3 per cent U-238 which has a fission threshold at 1.5 Mev—just high enough to be immune to fissioning by most neutrons released in the chain reaction. That's why the AEC separates U-235 from U-238 at its gaseous diffusion plants. The separation process produces fisionable U-235 at a cost of roughly $10,000 per pound. Uranium discarded in the separation process is known as "depleted uranium"; its cost is very small—probably only a few dollars per pound.

The superbomb's uranium jacket fissions under the torrent of fast neutrons. This produces an explosion almost simultaneous with that of the A-trigger. It would be expected to add an inwardly focused shock wave (implosion wave) to the reacting system. Moreover, it would add heat to the reacting core and thus accelerate the fusion reaction which is highly temperature sensitive. And finally, it would generate a vast outpouring of neutrons which would feed into Stages I and II.

All three stages occur almost simultaneously and are interdependent. Stage III enhances Stage I which in turn enhances Stage II.

Stages I and III both produce fission products of uranium whereas Stage II produces only fusion products. Thus the former constitute the dirty part of the bomb and the latter, the clean part.

Index of Dirtiness

The relative dirtiness of the bomb will depend upon the ratio of the energy released by fusion and fission. According to estimates made by the author, the March 1, 1954 explosion involved a fission yield of about 8 megatons. The total energy, i.e., fission plus fusion, has been estimated at 14 to 16 megatons. This would put the ratio of fusion to fission energy as roughly one-third to one-half. This means that the H-bomb of 1954 was, a very dirty bomb.

We turn now to the operational phases of bomb detonation. If a dirty bomb is exploded close to the earth's surface, so that the fire-ball comes in contact with the ground, then the fire-ball sucks up immense quantities of surface and sub-surface debris. Churned into the glowing fire-ball, the large debris particles become plated with the tiny fission products which are the main radioactive constituent of the fire-ball. Megaton-class bombs involve such explosive force that the bomb cloud pushes through the tropopause—the barrier between the stratosphere and the troposphere —and ascends to altitudes of 100,000 feet or more.

Large debris particles in the mushroom head of the bomb cloud seem to be responsible for most of the local fall-out, although some contribution comes from the cloud stem. The local fall-out is defined as that which comes to earth within a day or so, usually within a few hundred miles of the test site, although high stratospheric winds may elongate the elliptical fall-out pattern so that its axis stretches downwind many hundred of miles. This fall-out "can constitute a phenomenon of terrifying proportions" to use the words Dr. Libby voiced in telling the Holifield subcommittee about the hazard.

Bombs, burst high in the air (3 miles or more above the ground level), usually produce very little local fall-out. For example, the multimegaton bomb detonated by the U.S. on May 21, 1956, fulfilled these requirements. Thus even a dirty bomb can become clean under the proper circumstances. However, this cleanliness extends only to the local fall-out.

Stratospheric Hold-up

Remote or global fall-out has been carefully studied by *Project Sunshine* and by British experts as well. When uranium fissions, it produces three dozen different chemical elements as fission products, with a total of well over one hundred different radioactive isotopes. From the standpoint of global fall-out, the short-lived radioelements are of little concern since the hold-up time in the stratospheric reservoir is long enough for their radioactivity to burn out. Were the hold-up time not so long then the short-lived radioactivities would settle to earth and contribute significantly to radiation dose at the earth's surface. Incidentally, this long hold-up time does minimize genetic effects. The stratospheric retention of the longer-lived fission products is less significant for the long-lived fission products such as strontium-90 and cesium-137.

There seems to be some uncertainty as to the "residence time" of fission debris in the stratosphere. British measurements would indicate a fall-out of 10 to 20 per cent per year. Dr. Libby's data point to a longer hold-up time. Undoubtedly, our knowledge of the behavior of ultra-small-sized particles in the stratosphere needs much augmenting. It is probably true that there is a considerable fractionation of the various fission products depending on a number of factors. In the case of strontium-90, the worst danger among the fission products, it is significant that it is the granddaughter of krypton-90. Krypton is a noble gas which would be expected to diffuse widely throughout the fire-ball and cloud without firm attachment to any particles. It quickly disintegrates to rubidium, a highly active element; strontium arises from this latter parent, which has a half-life of about 3 minutes. Strontium-90 is the middle link in the fission chain which terminates with a stable form of zirconium. Having a half-life of 28 years, strontium-90 dominates the chain of decay products. Previous articles have spelled out the nature of the strontium hazard, the extent of which now seems to be emerging into the light of day. The next article in this series on fall-out will deal with the radiopoison hazard of nuclear explosives.

Fission of uranium and the production of strontium are inseparable. Conceivably, the fast fission of thorium might alter the strontium yield slightly, but this would not eliminate the hazard by any means. The real way to minimize strontium fall-out is to reduce the fission yield of the bomb.

Reduced Fall-out Weapons

Admiral Strauss' statement of July 19, 1956, cited in the editorial in this issue, spoke of the "development of weapons with reduced fall-out" and gave rise to speculation that the AEC had developed a pure fusion weapon.

Quite apart from the military considerations (which are presented in the editorial) one may look at both the fall-out from the *Operation Redwing* bombs and in some basic principles of fusion and fission weapons.

Japanese reports have noted the presence of U-237 in the early fall-out from our Pacific tests. This particular isotope of uranium does not occur in nature. U-237 is easily produced by fast neutron irradiation of U-238. Very fast neutrons produce what is known as an (n,2n) nuclear reaction—one neutron enters and two leave the uranium target nucleus. For this to happen the incident neutron has to have about 7 Mev of energy. Thus the identification of U-237 in fall-out proves that the weapon tested derived significant fission yield from the fast neutron effect in U-238.

Further *Sunshine* studies on strontium fall-out will also illuminate the nature of the weapons we tested in the Pacific this year. It is much too early to look for these data; but when they become available, we will be able to judge the degree of dirtiness of the weapons tested.

I believe that the *Redwing* tests in the Pacific probably succeeded in producing multimegaton explosions in which the fusion to fission energy ratio was raised. This would be an entirely logical development in view of the nature of the thermonuclear reaction. To return to the three stages of the superbomb, let us focus attention upon Stage II—the fusion phase of the bomb.

Fusion of light nuclei depends very strongly upon temperature. Raising the temperature of the reacting mass would fuse more of the light nuclei. Proper geometry and assembly techniques should permit elevating the core temperature and thus producing more fusion for the same investment in lithium deuteride. This would be desirable from the standpoint of wringing maximum yield from a given weight of weapon, and from the standpoint of reducing the release of fission products.

Strauss versus Holifield

The foregoing is consistent with the reply which Congressman Chet Holifield of California made to Adm. Strauss, July 25, referring to "the doctoring of present devices." Mr. Holifield asserted: "To issue this statement a distortion of fact was necessary, but this is of the least importance. I am concerned over the repeated pattern of applying advertising agency techniques to alleviate the natural fears of hydrogen destruction which trouble our people and the people of the world. Huckstering is no substitute for policy as we grope for solutions to the atomic and hydrogen dilemma."

Mr. Holifield, who as a member of the Atomic Energy Committee is supposed to be kept "fully and currently informed" by the AEC, commented on "the doctoring of present devices": "No matter how much you change an atomic or hydrogen weapon there is still a great deal of radioactivity. An atom bomb or hydrogen bomb burst on a military target without dangerous radioactive fall-out would be a miracle. Such a miracle has not been achieved."

It is interesting to look at the relative costs of the three phases of the bomb, especially if we think of the development of a pure fusion or sanitary weapon.

Dirty Bomb Is Dirt Cheap

Stage I involves the expensive fissionable material and presumably the expense for a reasonable trigger must run into the hundreds of thousands of dollars. This A-trigger represents an unavoidable, although reducible, dirty part of the bomb even in a "pure" weapon. However, it is small in radioactivity compared with that of the jacket.

Stage II involves fusion materials

> "Following my return from our Eniwetok Proving Grounds in the Marshall Islands, I have reported to the President on the results of the current weapons tests which are now nearing completion.
>
> "As a result of this series we have gained confirmation of important objectives stated by the President on April 25 just prior to the beginning of the tests. At his news conference on that date the President discussed our nuclear testing program, aimed at the development of a variety of weapons calculated to meet a wide range of military usage including defense against air attack. He noted that there was also the objective of making weapons with reduced fall-out.
>
> "Our tests to date have demonstrated that real progress has been made with respect to these objectives, including achievement of maximum effect in the immediate area of a target with minimum widespread fall-out hazard.
>
> "It has been confirmed that there are many factors, including operational ones, which do make it possible to localize to an extent not heretofore appreciated, the fall-out effect of nuclear explosions.
>
> "Thus the current series of tests has produced much of importance not only from a military point of view but from a humanitarian aspect.
>
> "We are convinced that mass hazard from fall-out is not a necessary complement to the use of large nuclear weapons."
>
> —LEWIS STRAUSS
> *Chairman, Atomic Energy Commission*
> *July 19, 1956*

for which no cost figures have been published. Nonetheless, costs can be estimated from the market price for lithium—with a lithium-6 content of 7.5 per cent—and the advertised prices for heavy water. The latter sells for $28 per pound. It is necessary to make some assumptions regarding the separation cost for lithium-6 but this should not be excessive since the isotopes Li^6 and Li^7 differ in mass by as much as 15 per cent and are therefore relatively easy to separate. My estimate for Li^6D is $400 per pound. Reactor-produced seed tritium would, of course, represent a high investment for Stage II, but one can assume that this will be nominal for regenerative weapons.

Stage III involves waste material from separation plants at Oak Ridge and its cost is negligible compared with the ingredients for Stages I and II. Making conservative assumptions about the fission yield in the jacket, one concludes that a ton of TNT equivalent can be produced in the jacket for a fraction of one cent.

It would undoubtedly be more expensive to construct a bomb without Stage III—that is, a jacketless H-bomb. And it would certainly be a much more difficult technical undertaking since the success of Stage II strongly depends upon the presence of the jacket. The neutron linkage and the cyclic nature of the multistage bomb make for a marriage between fission and fusion.

Dirtiness is a Relative Thing

In this marriage of fission and fusion the weapon designer has the ability to make either one the dominant partner. Fission in Stage III is relatively easy to maximize thus making for a very dirty bomb. Achievement of high internal temperatures raise the fusion to fission ratio. Since the temperature in the bomb varies as the bomb power, it would be expected that the ratio of fusion to fission could increase with increasing megatonage.

Fractional megaton-class weapons might have a ratio of one to one; i.e., equal yield from fission and fusion. Megaton-yield bomb could, if the designer wished, give the lion share of the energy to fusion. Multi-megaton weapons could be designed to raise this ratio even higher. Thus the relative dirtiness of the bomb could decrease for high-yield weapons. However, the absolute dirtiness of the bomb would increase since the number of fission products would increase.

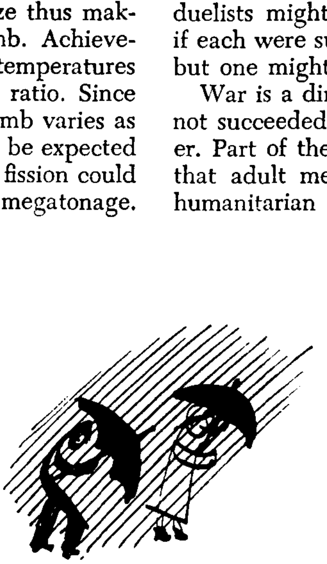
In summary, the superbomb can be designed to be either relatively clean or very dirty. The former would be desirable in the test series whereas the latter would seem to fulfill the requirement of a strategic weapon.

The *raison d'être* for a strategic weapon is to deter. That is the basic policy of our present "peace through mutual terror." To deter, the full terror of the weapon must be maximized. Diluting the potency of the bomb weakens the deterrence.

In the event that deterrence does not deter and the weapon power must be invoked, the military planners are not likely to handicap our strategic offensive by confining themselves to weapons with reduced fall-out. To do so would be to forego the immense potential of weapons now in stockpiles. The vast areas which fall-out can hit even if the blast heat of the bomb misses, makes the superbomb a most potent package. In addition, the persistence of the fission product fall-out adds new dimensions to war, i.e., denial of land to occupation.

The development of a cleaner superbomb presents the military with a choice of weapons. But the choice involves a matching of weapons. Two duelists might both select cap pistols if each were sure of the other's choice, but one might draw a shotgun too!

War is a dirty business. Science has not succeeded in making it any cleaner. Part of the madness of our time is that adult men can use a word like humanitarian to describe an H-bomb.



Editorial: H-Bombs without Fall-out

(Continued from page 234)

bombs, in which the fission yield of the "detonator" is multiplied a thousandfold by the fission of uranium-238 in the envelope. A well-known science reporter recently wrote from the Pacific test area that the AEC has never used any bombs of the latter type and even called them "fission-fusion-fiction" bombs. Circumstantial evidence refutes this: the officially acknowledged extent of the fall-out in last year's test series, the extensive precautions taken in the present series to avoid repetition of the mishaps which occurred last year, the Japanese observations of certain heavy elements in the fall-out, etc. Considerations of economy (a thermonuclear bomb is only worthwhile if it costs much less than a thousand atomic bombs) and of space (a ton of uranium takes so much less space than a ton of hydrogen or lithium hydride) explains why American tests must have been carried out, at least in part, with bombs in which the fission of cheap compact uranium served as the main source of energy. In all likelihood, work on "pure" heavy hydrogen bombs has not been neglected, and some such devices may have been tested in the Pacific; but there is no reason to hope that the "inhuman" uranium bombs will be displaced by the "humanitarian" (how relative such terms can become!) hydrogen bombs.

Mr. Strauss' announcement—as well as the whole information policy of the AEC in the thermonuclear bomb and radioactive fall-out areas—may be attributed to two desires: not to cause public hysteria in America and abroad, and not to strengthen the world-wide agitation for the cessation of weapon tests. The first aim seems to us thoroughly mistaken—public complacency is, in our opinion, at the present juncture, a much greater danger than public hysteria. As to the second aim, even those who agree with Mr. Strauss (and President Eisenhower), that America cannot stop the development of improved nuclear weapons except as part of an agreed (and effectively controlled) disarmament plan, should find it utterly wrong to pursue this aim by confusing public thinking in a field so crucial for the whole future of mankind.

—E. R.